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Research Article

Evaluating Enviromental Mitigatio and Sustainability Practices in the Construction of the Trans-Sumatera Toll Road

Arief Andriansyah[1,a*)] Ridwan M Abduh[2)] Galuh Paramita[3)]

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Abstract

The construction of the Trans-Sumatera Toll Road, part of Indonesia's National Strategic Projects (PSN), offers significant economic benefits but also poses environmental challenges, particularly air pollution from construction activities. This study evaluates air quality deterioration due to heavy machinery use, material transportation, and excavation. A quantitative approach was employed through field surveys, environmental monitoring, and laboratory analysis. Air quality monitoring was conducted at eight locations using Graseby Dust Samplers and Gas Impingers to measure PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, and HC, following Government Regulation No. 41/1999. Results indicate that PM_{10} levels (22 µg/Nm³) remained within regulatory limits, while CO (578 µg/Nm³) and NO_2 (35.6 µg/Nm³) fluctuated with construction intensity. Mitigation strategies such as water spraying and project vehicle management effectively reduced dust and gas emissions. Continuous monitoring is essential to minimize air pollution impacts. This study provides empirical data to support sustainable infrastructure development, balancing economic benefits with environmental conservation.

Keywoards: Air pollution, construction, Trans-Sumatera Toll Road, environmental mitigation, sustainable infrastructure.

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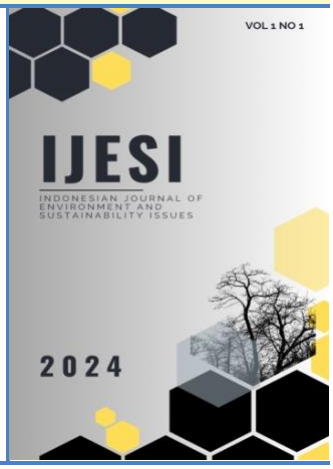

INTRODUCTION

The construction of the Trans-Sumatera Toll Road, as part of the National Strategic Projects (PSN), aims to accelerate economic growth and enhance connectivity across regions in Sumatra. Spanning over 2,700 kilometers, this toll road connects Bakauheni in Lampung to Banda Aceh. The project is expected to deliver significant economic benefits, such as reducing logistics costs, boosting investments, and promoting equitable regional development. However, despite these advantages, this large-scale infrastructure development also poses substantial environmental and social challenges for communities along the route. [1], [2], [3]. The primary impacts often observed from infrastructure development include increased air pollution caused by the operation of heavy machinery and material transportation, as well as a decline in air quality resulting from construction activities. Air pollution and noise are pressing concerns because they are not merely abstract figures on a chart or distant threats but tangible aspects that are audible, inhalable, and directly affect our daily lives. Air pollution can be measured not only by the increase in particulate matter generated by construction activities but also by noise levels, expressed in decibel meters, which serve as an additional parameter indicating a rise in air pollution [4]. This highlights that air pollution encompasses both physical and acoustic dimensions, both of which have significant impacts on environmental quality and the well-being of communities surrounding the construction sites.

In relation to previous research, the impact of air pollution resulting from toll road construction projects has been the focus of several studies. Earlier research indicates that construction activities, such as the operation of heavy machinery, material transportation, and land excavation, can significantly increase the concentration of particulate matter (PM10) and other air pollutants. A study conducted by Munggaran revealed that air pollution in DKI Jakarta, associated with construction activities, contributed to a rise in pneumonia cases among children under five, highlighting the importance of controlling PM10 and CO concentrations to protect public health [5]. Additionally, research by Artana and Ngurah emphasized that air pollution caused by traffic, including construction activities, poses significant health risks, particularly respiratory issues, due to exposure to pollutants such as PM10 and PM2.5 [6]. In the specific context of toll road construction projects, it has been identified that the Solo-Yogyakarta toll road construction project caused road damage due to heavy vehicles and potentially increased air pollution in the surrounding area. This aligns with findings indicating that during the construction phase, PM10 concentrations can rise to 50 µg/Nm³, exceeding the regulatory limit set by Government Regulation No. 41/1999 of 35 µg/Nm³ [7]. This air pollution not only affects the physical environment but also poses risks to public health, particularly for construction workers and communities living near the project [8].

Furthermore, related studies have shown that factors such as wind speed, rainfall, and the type of materials used in construction can influence the level of air pollution. Material transportation activities are also a major contributor to vehicle emissions, increasing levels of nitrogen oxides (NOx) and carbon monoxide (CO), which can further degrade air quality at construction sites. In the context of the Trans-Sumatera Toll Road, this data is relevant to understanding that although the average PM10 concentration recorded during construction remains within safe limits (22 µg/Nm³), the risk of increased air pollution persists, especially if construction activities are not managed properly. Previous studies have also emphasized the importance of implementing environmentally friendly technologies, such as using low-emission heavy equipment, water

spraying to suppress dust, and regular air quality monitoring, to mitigate the negative impacts of toll road construction on air quality. Therefore, this study adopts an integrated approach to evaluate air pollution impacts holistically and assess the effectiveness of mitigation strategies that have been implemented, drawing on findings and recommendations from previous research as a foundation to support sustainable infrastructure development.

METHODS

This study adopts a quantitative approach utilizing field surveys, environmental monitoring, and laboratory analysis, focusing on air quality impacts caused by increased construction activities in the Trans-Sumatera Toll Road project. The research methodology is designed to specifically and integratively evaluate air quality issues by tailoring data collection, implementation, and analysis to address relevant air pollution challenges.

1. Data Collection

a. Field Surveys
   Field surveys were conducted to map construction sites, areas with high construction activity, and strategic air quality monitoring points. The survey also included identifying primary sources of air pollution, such as heavy machinery, project vehicles, and material transportation.
b. Air Quality Measurement
   Air samples were collected periodically from strategic locations directly impacted by construction activities. Measurements were conducted using a Graseby Dust Sampler for particulate matter (PM10 and PM2.5) and a Gas Impinger for gaseous pollutants such as SO_2, NO_2, CO, and HC. These measurements adhered to standards set by Government Regulation No. 41/1999 on Air Pollution Control.
c. Construction Activity Data
   Data on the intensity of heavy equipment use, material transportation frequency, and construction activity duration were collected to understand the correlation between construction activities and increased air pollution.

2. Implementation and Monitoring

a. Air Quality Monitoring
   Monitoring was conducted quarterly during the construction phase at multiple measurement points representing high-construction activity areas and nearby residential zones. This monitoring aimed to track consistent concentrations of air pollutants such as PM10, PM2.5, and gaseous emissions.
b. Monitoring the Effectiveness of Mitigation Measures
   An evaluation was conducted on mitigation measures such as water spraying to suppress dust, installation of dust barriers, and the use of low-emission heavy equipment.
c. Interviews with Nearby Communities
   Structured interviews were carried out with communities living near the project site to identify the direct impact of air pollution on their health and comfort.

3. Data Analysis

a. Air Quality Data
   The concentrations of air pollutants were analyzed descriptively by comparing measurement results against the thresholds set by Government Regulation No. 41/1999. Trends in pollutant concentration changes were identified to understand patterns and levels of air pollution risk.
b. Effectiveness of Mitigation Measures
   The effectiveness of mitigation measures was analyzed by comparing pollutant concentrations before and after implementing mitigation strategies. This analysis determined whether the measures effectively controlled the rise in air pollution.
c. Correlation Between Construction Activities and Air Pollution
   A correlation analysis was conducted between construction activity data, such as heavy equipment usage frequency and material transportation, and the levels of air pollutant concentrations.

RESULT AND DISCUSSIONS

Air Quality

The primary impact being monitored is the potential decline in air quality around the project area. The monitored sources of impact include ambient air in areas near the project site, particularly those close to residential areas. Pollutants are primarily generated by construction activities, such as mobilization and earthworks. Environmental parameters for ambient air monitoring are based on Government Regulation (PP) No. 41 of 1999 on Air Pollution Control. The purpose of monitoring is to prevent air quality degradation due to construction operations and to maintain good air quality around the construction site.

The methods used for air quality measurement include:

1. Graseby (dust sampler): For sampling dust and lead (Pb).
2. Gas Impinger: For sampling ambient air, including gases such as SO_2 (Sulfur Dioxide), CO (Carbon Monoxide), NO_2 (Nitrogen Dioxide), and HC (Hydrocarbons).

The air quality data collection survey for the toll road construction project was conducted at eight different locations. The data and analysis results for air quality are presented in Tables 1 to 7 as follows.

Table 1. Air Quality Testing at STA 14+400

Type of Testing: Air Quality Testing					
Phase: Construction					
Testing Frequency: Every 6 months					
Sampling Location		Desa Tetaan STA 14+400			
Sampling Point Name		Trans Sumatera Toll Road Project Section Bakter Package 1			
Koordinat	**LS**	05°45’32,16”			
	BT	105°42’40,17”			
Periode		July-December 2018			
Tanggal Pengujian		24 November 2018			
No	**Parameter Uji**	**Standart (Penajaman 8 Jam)**			**Measurement Result**
		Threshold Limit	**Unit**	**Measurment Duration**	

		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	2
2	CO	30.000	µg/Nm^3	1 hour	655
3	NO_2	400	µg/Nm^3	1 hour	29
4	O_3	235	µg/Nm^3	1 hour	1
5	HC	160	µg/Nm^3	3 hours	15
6	TSP (Dust)	230	µg/Nm^3	24 hours	14

Table 2. Air Quality Testing at Bakauheni Selatan Toll Gate

Type of Testing: Air Quality Testing		
Phase: Construction		
Testing Frequency: Every 6 months		
Sampling Location		Bakauheni Selatan Toll Gate
Sampling Point Name		Trans-Sumatera Toll Road Project Section Bakter Package 1
Coordinates	**LS**	05°50'35,8"
	BT	105°43'41,3"
Period		July-Desember 2018
Testing Date		20 November 2018

No	Parameter Uji	Standard (8-Hour Focus)			Measurement Result
		Threshold Limit	Unit	Measurement Duration	
		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	<15
2	CO	30.000	µg/Nm^3	1 hour	497
3	NO_2	400	µg/Nm^3	1 hour	25,3
4	Partikel < 10 µm (PM_{10})	150	µg/Nm^3	24 hours	22
5	O_3	235	µg/Nm^3	1 hour	29,5
6	HC	160	µg/Nm^3	3 hour	14,7
7	Partikel <2,5 µm ($PM_{2,5}$)	65	µg/Nm^3	24 hour	10
8	Pb (Timah Hitam)	2	µg/Nm^3	24 hour	<0,8
9	TSP (Debu)	230	µg/Nm^3	24 hour	51

Table 3. Air Quality Testing at Bakauheni East Toll Gate

Type of Testing: Air Quality Testing		
Phase: Construction		
Testing Frequency: Every 6 months		
Sampling Location		Bakauheni East Toll Gate
Sampling Point Name		Trans-Sumatera Toll Road Project Section Bakter Package 1
Coordinates	**LS**	05°50'35,8"
	BT	105°43'41,3"
Period		July-Desember 2018
Testing Date		20 November 2018

No	Parameter Uji	Standard (8-Hour Focus)			Measurement Result
		Threshold Limit	Unit	Measurement Duration	
		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	<15

2	CO	30.000	µg/Nm^3	1 hour	578
3	NO_2	400	µg/Nm^3	1 hour	35,6
4	Partikel < 10 µm (PM_{10})	150	µg/Nm^3	24 hours	25
5	O_3	235	µg/Nm^3	1 hour	15,8
6	HC	160	µg/Nm^3	3 hour	58
7	Partikel <2,5 µm ($PM_{2,5}$)	65	µg/Nm^3	24 hour	11
8	Pb (Lead)	2	µg/Nm^3	24 hour	<0,8
9	TSP (Total Suspended Particles)	230	µg/Nm^3	24 hour	51

Table 4. Air Quality Testing at STA 74+395

Type of Testing: Air Quality Testing					
Phase: Construction					
Testing Frequency: Every 6 months					
Sampling Location		Area Jalan Ir. Sutami STA 74+395			
Sampling Point Name		Trans-Sumatera Toll Road Project Section Bakter Package 2			
Coordinates	**LS**	05°24'04,88"			
	BT	105°21'20,48"			
Period		July-Desember 2018			
Testing Date		25 November 2018			
No	**Parameter Uji**	**Standard (8-Hour Focus)**			**Measurement Result**
		Threshold Limit	**Unit**	**Measurement Duration**	
		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	<15
2	CO	30.000	µg/Nm^3	1 hour	407
3	NO_2	400	µg/Nm^3	1 hour	18,3
4	Partikel < 10 µm (PM_{10})	150	µg/Nm^3	24 hours	1,1
5	O_3	235	µg/Nm^3	1 hour	10,3
6	HC	160	µg/Nm^3	3 hour	27
7	Partikel <2,5 µm ($PM_{2,5}$)	65	µg/Nm^3	24 hour	-
8	Pb (Lead)	2	µg/Nm^3	24 hour	76
9	TSP (Total Suspended Particles)	230	µg/Nm^3	24 hour	0,8

Table 5. Air Quality Testing at Gerbang Tol Lematang

Type of Testing: Air Quality Testing					
Phase: Construction					
Testing Frequency: Every 6 months					
Sampling Location		Gerbang Tol Lematang			
Sampling Point Name		Trans-Sumatera Toll Road Project Section Bakter Package 2			
Coordinates	**LS**	05°24'04,88"			
	BT	105°21'20,48"			
Period		July-Desember 2018			
Testing Date		25 November 2018			
		Standard (8-Hour Focus)			

No	Parameter Uji	Threshold Limit	Unit	Measurement Duration	Measurement Result
		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	<15
2	CO	30.000	µg/Nm^3	1 hour	521
3	NO_2	400	µg/Nm^3	1 hour	22,6
4	Partikel < 10 µm (PM_{10})	150	µg/Nm^3	24 hours	1,4
5	O_3	235	µg/Nm^3	1 hour	15,1
6	HC	160	µg/Nm^3	3 hour	26
7	Partikel <2,5 µm ($PM_{2,5}$)	65	µg/Nm^3	24 hour	14
8	Pb (Lead)	2	µg/Nm^3	24 hour	<0,8
9	TSP (Total Suspended Particles)	230	µg/Nm^3	24 hour	51

Table 6. Air Quality Testing at Desa Jatimulyo

Type of Testing: Air Quality Testing		
Phase: Construction		
Testing Frequency: Every 6 months		
Sampling Location		Desa Jatimulyo, Bandar Lampung
Sampling Point Name		STA 84+304
Coordinates	**LS**	05°19’56,30”
	BT	105°17’35,09”
Period		09 oktober 2017
Testing Date		

No	Parameter Uji	Standard (8-Hour Focus)			Measurement Result
		Threshold Limit	Unit	Measurement Duration	
		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	34
2	CO	30.000	µg/Nm^3	1 hour	3780
3	NO_2	400	µg/Nm^3	1 hour	38
4	Partikel < 10 µm (PM_{10})	150	µg/Nm^3	24 hours	
5	O_3	235	µg/Nm^3	1 hour	91
6	HC	160	µg/Nm^3	3 hour	
7	Partikel <2,5 µm ($PM_{2,5}$)	65	µg/Nm^3	24 hour	
8	Pb (Lead)	2	µg/Nm^3	24 hour	0,09
9	TSP (Total Suspended Particles)	230	µg/Nm^3	24 hour	88

Table 7. Air Quality Testing at STA

Type of Testing: Air Quality Testing		
Phase: Construction		
Testing Frequency: Every 6 months		
Sampling Location		Area Direksi KEET Zona 1 Paket 3 Bandar Lampung
Sampling Point Name		STA 106+300
Coordinates	**LS**	05°10’44,03”
	BT	105°12’30,27”
Period		June-December 2018

Testing Date		22 November 2018			
No	Parameter Uji	Standard (8-Hour Focus)			Measurement Result
		Threshold Limit	Unit	Measurement Duration	
		PP RI No. 41/1999			
1	SO_2	900	µg/Nm^3	1 hour	32
2	CO	30.000	µg/Nm^3	1 hour	3666
3	NO_2	400	µg/Nm^3	1 hour	35
4	Partikel < 10 µm (PM_{10})	150	µg/Nm^3	24 hours	
5	O_3	235	µg/Nm^3	1 hour	83
6	HC	160	µg/Nm^3	3 hour	
7	Partikel <2,5 µm ($PM_{2,5}$)	65	µg/Nm^3	24 hour	
8	Pb (Lead)	2	µg/Nm^3	24 hour	0,08
9	TSP (Total Suspended Particles)	230	µg/Nm^3	24 hour	81

The air quality data obtained from the Bakauheni Utara Toll Gate during the construction phase of the Bakauheni-Terbanggi Besar Toll Road provides a comprehensive overview of the potential environmental impacts generated by construction activities in large-scale infrastructure projects. This project, as part of the national strategic program, involves intensive construction activities, including the use of heavy machinery, material transportation, and earthworks, which have the potential to emit gases and particles. Therefore, air quality monitoring at this location is a crucial step to identify pollution sources, measure emission levels, and evaluate the effectiveness of the mitigation measures implemented.

Construction activities, particularly in large-scale infrastructure projects like toll roads, often have a significant impact on the surrounding air quality. Emissions of gases and particulate matter generated by heavy machinery, material transportation, and earthworks are among the primary sources of air pollution. Previous studies have highlighted that emissions from construction sites can directly affect air quality and, if not managed properly, can worsen the health conditions of nearby communities [9]. Therefore, evaluating environmental impacts and implementing effective mitigation strategies are essential steps to ensure sustainable development.

Construction Impacts on Air Quality

Construction sites are often major sources of air pollution due to emissions of suspended particulate matter (TSP), carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). A study by identified that dust emissions from construction activities contribute significantly to increased $PM_{2.5}$ concentrations in urban areas, which can elevate the risk of respiratory disorders [10]. Additionally, research showed that infrastructure projects in urban environments could increase $PM_{2.5}$ levels by up to 30% found that heavy vehicle emissions during material transportation could raise CO concentrations by as much as 40% in project areas. These findings underscore that construction emissions can extend beyond localized impacts, affecting nearby communities and exacerbating overall air quality. This highlights the urgent need for regular monitoring and targeted mitigation measures.

The Importance of Air Quality Monitoring

Monitoring air quality during the construction phase is crucial for understanding the extent of environmental impacts. Emphasized that periodic monitoring enables the identification of pollution sources and quantification of emissions generated by construction activities, such as heavy machinery use and material transport [11]. An effective monitoring system also supports air quality predictions, particularly in areas affected by construction [12]. For instance, air quality data from the Bakauheni Utara Toll Gate during the construction phase of the Bakauheni-Terbanggi Besar Toll Road revealed that despite intensive construction activities, the concentrations of SO_2 (<15 µg/Nm³), CO (578 µg/Nm³), NO_2 (35.6 µg/Nm³), and PM_{10} (25 µg/Nm³) remained well below the thresholds set by Government Regulation No. 41 of 1999. This indicates the effectiveness of the mitigation measures implemented.

Mitigation Measures and Policies

Evaluating the effectiveness of mitigation measures is a vital aspect of environmental impact management. Measures such as the use of low-emission fuels, regular maintenance of heavy machinery, covering transported materials, and road wetting to suppress dust have proven to be effective in reducing air pollution [13] highlighted that adopting environmentally friendly technologies, such as air filtration systems at construction sites, can reduce emissions by up to 25%. Implementing data-driven policies, including real-time emission monitoring and community engagement, also enhances the effectiveness of environmental management strategies [14]. The following mitigation measures have been implemented to reduce air pollution caused by toll road construction activities:

1. Covering the beds of trucks/vehicles transporting materials (such as sand, fill soil, and excavated soil) with tarpaulins or plastic sheets to prevent the spread of dust particles into the environment and are presented in Figure 1. [5].

Figure 1. Covering construction materials.

2. Restricting the speed of project vehicles, especially on entry and exit roads to the project site (between 20-40 km/h) and are presented in Figure 2. [15], [16].

Figure 2. Restricting the speed of project vehicles

3. Cleaning and monitoring the tires of project vehicles (material transport trucks) before they leave the project site to prevent the spread or spillage of soil onto the surrounding environment and public roads and are presented in Figure 3. [5], [17].

Figure 3. Cleaning and monitoring the tires of project vehicles

4. Spraying water in project site areas and along material transport routes to suppress dust and mitigate soil spillage resulting from transportation activities and are presented in Figure 4. [6].

Figure 4. Spraying water in project site.

CONCLUSION

This study evaluates environmental mitigation measures and sustainability practices in the construction of the Trans-Sumatera Toll Road, focusing on air pollution resulting from construction activities. Air quality monitoring at eight locations indicates that while PM_{10} (22–25 µg/Nm³) and $PM_{2.5}$ (10–14 µg/Nm³) concentrations remain within safe limits based on Government Regulation No. 41/1999, fluctuations in CO (407–3,780 µg/Nm³) and NO_2 (18.3–38 µg/Nm³) levels are directly linked to the intensity of heavy equipment usage and material transportation frequency. The implementation of mitigation strategies, including water spraying, dust barriers, vehicle speed restrictions (20–40 km/h), and tire cleaning before leaving the project site, has proven effective in reducing particulate emissions and gas pollutants. However, analysis results indicate that although most air pollutant parameters remain within regulatory limits, increased construction activities have the potential to cause emission spikes that may affect air quality in surrounding project areas. Therefore, continuous air quality monitoring, the adoption of low-emission construction equipment, and data-driven environmental policies are essential strategies to ensure a balance between infrastructure development and environmental conservation. These recommendations serve as a foundation for sustainable infrastructure planning that prioritizes economic benefits without neglecting environmental impacts.

AUTHORS INFORMATION

Corresponding Authors

Arief Andriansyah – Civil Engineering Department, Faculty of Engineering, Diponegoro University
Email: ariefandriansyah@lecturer.undip.ac.id

Authors

Ridwan M Abduh – Department of Infrastructure 3, Division 1 PT. Waskita Karya (Tbk).
Email: ridwan.abduh@waskita.co.id

Authors

Galuh Paramita – Civil Engineering Department, Faculty of Engineering dan Computer Science, Teknokrat Indonesia University
Email: galuh.paramita@teknokrat.ac.id

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